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QUANTITATIVE STUDIES OF BACTERIAL POLLUTION AND NATURAL PURIFICATION IN THE OHIO AND ILLINOIS RIVERS

J. K. Hoskins

Robert A. Taft Sanitary Engineering Center
Cincinnati, Ohio

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QUANTITATIVE STUDIES OF BACTERIAL POLLUTION AND NATURAL PURIFICATION IN THE OHIO AND ILLINOIS RIVERS.

By

J. K. Hoskins, Sanitary Engineer,
United States Public Health Service.

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QUANTITATIVE STUDIES OF BACTERIAL POLLUTION AND NATURAL PURIFICATION IN THE OHIO AND THE ILLINOIS RIVERS.

The Public Health Service has been engaged for some years in studies of various phenomena concerned with the pollution and natural purification of streams. One general purpose of these studies has been to evaluate the intensity of bacterial pollution to be expected from known populations discharging sewage into streams of known discharge and velocity of flow. With this end in view we have collected detailed bacteriological data from two streams of quite different types, the Ohio and Illinois Rivers. Published observations on the Ohio River* covered a period of three

* A Study of the Pollution and Natural Purification of the Ohio River. II. Report on Surveys and Laboratory Studies. (1924). Public Health Bulletin No. 143, U. S. Public Health Service, Washington, D. C.

years, while those of the Illinois River were continued for a complete year, so that in each case information was obtained throughout an entire seasonal cycle.

From a consideration of the data of these studies, some general tendencies in bacterial changes are indicated, which may be of assistance to sanitary engineers in forming an estimate of the effect, both immediate and prolonged, of adding sewage, from a definite population, to a watercourse of determined hydrometric characteristics.

The degree of bacterial pollution contributed by cities, about which information is most generally desired, may be separated into one of two principal cases. The first case is concerned with the intensity of bacteria that will result in the stream in the zone of highest pollution below the point at which the sewage is discharged. The second, and sometimes more important consideration, is the proportion of such contributed bacteria that will remain in the stream at a known distance, or time of flow, below the point at which they were added.

Discussion.

Due to fluctuations in discharge and inflow of all streams, the bacterialconcentration resulting from a constant rate of contribution may vary widely. It is essential therefore for a comparative study of results that not only the concentration of bacteria be considered but that the actual quantities of organisms be taken into account as well. The quantities of bacteria present in, or added to, a watercourse can be most conveniently expressed in terms of a unit in which is combined the elements of volume, time and bacterial concentration. Such a unit, called the "Quantity Unit," has been used for this purpose. The Quantity Unit may be defined to be the product of one cubic foot discharge per second and a concentration of 1000 bacteria per cubic centimeter. Hence the number of quantity units of bacteria in a stream equals:

$$\frac{\text{discharge in second-feet} \times \text{bacteria per c.c.}}{1000}$$

Obviously this unit is convertible into bacterial numbers per unit of time such as the day. Thus an average of 1000 bacteria per cubic centimeter in a flow of one second-foot for one day, or 86,400 seconds, is equivalent to 28,317 (= number of c.c's. in one cubic foot) x 1000 x 86,400, or 2,446,589,000,000 bacteria per day in one quantity unit.

Immediate Pollution.

In observations of the effect of pollution by sewered communities, it has been noted consistently that the zone of greatest bacterial density in the receiving stream does not occur immediately below the sewer outfalls, but at a point from 10 to 30 hours downstream from the place where such pollution is added. Moreover the location of this maximum zone seems to be influenced by seasonal temperatures, being furthest downstream during the winter months. Whether an actual multiplication of organisms in the stream takes place until this maximum is reached, or whether the observed increase in bacterial numbers is due to the physical separation of organic matter, has not been definitely determined, though the evidence seems to point to the former assumption as the most logical explanation.

Observations extending over the entire seasonal cycle have been made of the numbers of bacteria per capita added to the stream by the sewage pollution from Cincinnati,

Louisville, Chicago and Peoria. In each instance the numbers appear to vary with seasonal temperature conditions, being considerably greater in summer than in winter. These seasonal fluctuations are shown for each of the four cities, both in terms of quantity units per capita and in billions of bacteria per capita per day, in Table No. 1, wherein the values for summer, for winter, and averages for the entire year, are presented.

(Insert Table No. 1)

By combining the yearly per capita contributions of gelatin, of agar and of B.coli counts, respectively, of all of the four cities, a general average figure is obtained which may be considered to be roughly representative of the annual average quantity units of the respective types of bacteria contributed to these streams per capita of the sewered population.

The variation from month to month in the numbers of bacteria contributed is, in general, reasonably consistent, increasing quite rapidly to a maximum in June or July and declining again gradually until October and then more rapidly to the lower numbers found throughout the winter season. These changes in the contribution of B. coli from each of the four cities are shown in more detail in Table No. 2, in which the figures represent the ratio of the count each month to the annual average, the latter being taken equivalent to 100. The averages of the ratios for these four cities for corresponding months represent what might be considered a general measure of the degree of change from month to month in numbers of B.coli contributed by urban sewered population. Similar averages have been derived for the monthly variations in numbers of bacteria growing on gelatin at 20°C. in 48 hours and on agar at 37°C. in 24 hours, all of which are assembled in Table No. 3, and plotted in Figure No. 1. For purposes of comparison, the average monthly river water temperatures are also given in the tables.

(Insert Tables Nos. 2 and 3)

(Insert Fig. No. 1)

If now these average values as above derived are representative of the bacterial changes in streams in general, as brought about by sewage pollution, they supply a ready means of estimating the maximum concentration

of bacteria to be expected in a stream of known discharge resulting from the sewage of a known population. The bacteria per cubic centimeter thus added can be computed at once by the relationship:

$$\text{Bacteria per c.c. added} = \frac{\text{population x quantity units per capita}}{\text{discharge in thousands of second-feet}}$$

As an example, the average yearly numbers per c.c. of B.coli contributed by Cincinnati, with a sewered population of 494,300, to the Ohio River, where the mean annual flow is 97,500 second-feet, is:

$$\frac{494{,}300 \times 0.1018}{97.5} = 516 \text{ B.coli per c.c.}$$

Similarly the concentration for any season or month may be estimated by applying to the yearly average the proper seasonal factor given in Table No. 3. Thus in July, when the discharge of the Ohio River is 19,000 second-feet, the estimated concentration of B.coli contributed by Cincinnati would be:

$$\frac{494{,}300 \times 0.1018 \times 3.01}{19.000} = 5{,}320 \text{ per c.c.}$$

Applying this method of estimation to the four cities of Cincinnati, Louisville, Chicago and Peoria, it is possible to compare directly the computed concentrations of bacteria to be expected in each case with the densities actually observed to have resulted from the sewage pollution contributed. Such a comparison of computed and observed concentrations of B.coli is presented in Table No.4, together with the average monthly rates of stream discharge and other related data. It will be noted that, while the estimated concentrations for some individual months differ quite widely from those actually observed, yet the two sets of values are in the main comparable and generally of the same degree of magnitude. Bearing in mind that the actual enumeration of B.coli is subject to considerable variation, it would appear that the use of the formula as a rough working model may be justified.

(Insert Table No. 4)

Rates of Decrease in Bacterial Pollution.

Quite extensive observations of the decrease of bacteria in polluted waters indicate that such changes follow a fairly regular course, modified by variations in environment such as temperature and other factors but yet having an orderly arrangement of reduction. Just what agency is primarily responsible for the death of such bacteria has not been definitely determined. However, there is considerable evidence suggesting that plankton activity rather than lack of food supply is the dominant influence in bacterial diminution.*

* The effect of Plankton Animals upon Bacterial Death Rates. By W.C.Purdy and C.T.Butterfield. American Journal of Public Health, Vol. VIII, No. 7, July,1918, pp. 499-505.

A simple and direct method for determining the rates of bacterial decrease in streams, if it were practicable, would be to observe the changes occurring in stored samples of the water under consideration. Unfortunately the decreases in such stored samples do not correspond invariably with the natural rates occurring in the stream. Long-continued efforts, still in progress, to place the study of bacterial death rates upon such an experimental basis, have thus far not been successful. Resort must then be made to the observation of natural purification occurring in streams. Under such conditions, all modifying factors are impossible of accurate control and in many cases corrections for them can be applied only in an approximate manner. Therefore, rates of decrease so determined must necessarily be interpreted with these limitations clearly understood.

Studies of natural purification of the Ohio River presented in detail in Public Health Bulletin 143 indicate that changes in the bacterial content between Cincinnati and Louisville are quite orderly and that the rates of decrease can be represented in a general way by empirical curves and formulae. Similar observations on the Illinois River have tended to confirm this conclusion and have indicated that such changes may be of rather general occurrence, rather than confined to these two streams. The rates of decrease in all instances are not directly comparable, however, and, as stated in the publication above referred to, these rates must be considered as approximate only, since they apparently are modified by other factors such as density or concentration, and perhaps also by relative age or staleness of the sewage contributed. It is certain at least that the rates of bacterial decrease from the point of maximum concentration in the Ohio River are quite different from those observed in the Illinois. However,

when the disparity in initial concentrations is taken into account and comparisons made at points of equal bacterial density, the rates coincide much more closely. This condition is perhaps best illustrated by the summer rates of decrease in bacteria growing on agar at 37°C. as observed in the Ohio, in the Illinois River below Chicago, and again below Peoria, the base data of which are given in Table No. 5. Figure No. 2 shows these rates plotted from the same origin, while Figure No. 3 shows the same curves shifted so that at the points of maximum concentration they coincide with the corresponding density of the upper Illinois curve.

(Insert Table No. 5)

(Insert Figures Nos. 2 and 3)

While such an adjustment according to maximum density brings the rates into closer harmony, characteristic preliminary decreases, probably due to other unknown factors, are still evident in each of the curves. It may finally prove to be impracticable therefore to develop a composite expression or curve defining accurately the general rate of bacterial decrease in all streams. A series of such expressions or curves, taking into consideration various modifying factors, may be found to best portray the actual rates of most probable change.

However the decreases in bacterial numbers are in a broad way quite similar, and it is possible, from the available data collected, to indicate the general trend of such decrease. Such a general rate of purification, if applicable to a specific case, may assist in forming an estimate of the redative numbers of bacteria that may be expected to survive in the stream after any definite interval of time.

Such general rates of decrease for B.coli, under both summer and winter seasonal conditions, have been outlined by the data of the Ohio and Illinois River studies, and are assembled in Tables Nos. 6 and 7. The Illinois River rates of decrease were derived from observations of the upper Illinois River in which the sewage of Chicago is the agency of pollution, while the lower Illinois River is concerned principally with the pollution introduced by the metropolitan district of Peoria. Daily observations at successive downstream sampling stations were averaged over both the summer and winter seasons, and smooth curves defining the rates of natural purification were drawn through these experimentally determined results, plotted on semi-logarithmic

paper. The method of obtaining the Ohio River rates of decrease is described in the Public Health Bulletin above referred to. In addition to these general curves of the Ohio, data defining rates of purification at different maximum densities of bacterial content are presented in Table No. 114 of that publication, wherein are tabulated observations of bacterial numbers at successive sampling stations grouped according to volume of discharge of the river. By grouping these data according to initial concentration and by times from origin, average densities for each group have been obtained at various average intervals of time in hours from the point of maximum density. The results of such grouping for different initial densities are also presented in Tables Nos. 6 and 7 for summer and for winter respectively, and define average rates of decrease of B.coli starting from the various maximum concentrations.

(Insert Tables Nos. 6 and 7)

If now these data are plotted on semi-logarithmic paper, in which the concentrations of B.coli are plotted as ordinates on the logarithmic scale and the times from maximum concentration as abscissae on the plain scale, it will be observed that these points define, in a general way, fairly smooth curves, all of which have the same general trend. It may be noted also that the curves of winter purification are of much flatter slope than are those of summer, indicating that natural purification proceeds at much slower rates during cold weather. It is entirely possible, therefore, regardless of the generally lower numbers of bacteria contributed during the winter season, that the critical or most severe period of bacterial pollution to be expected from a given sewage discharged upstream may occur during the winter, rather than during the summer. This is of course the reverse of what would be expected of the critical oxygen depletion condition resulting from the same sewage pollution.

Having obtained the general rates of decrease in B.coli for various initial concentrations, it is possible to interpolate intermediate rates of decrease, starting from definite initial concentrations. Such interpolated rates should, in a general way, indicate the numbers of B.coli that may be expected to survive after definite intervals of time have elapsed beyond the point of greatest bacterial density in the stream. Such rates of decrease are for convenience placed in tabular form for ready reference in Tables Nos. 8 and 9, the former representing summer conditions

and defining numbers of bacteria remaining after definite intervals of time, starting from various densities at the maximum point, and the latter table presenting the same data for winter months.

(Insert Tables Nos. 8 and 9)

However, before such estimates can be accepted with complete confidence, it is obviously necessary that they be checked by observations on a considerable number of streams of different physical characteristics. The empirical results here presented outline what our observations thus far have indicated to take place and endeavor to suggest their practical application. The explanation of the phenomena concerned in such changes must await additional research.

SUMMARY.

Quite extended observations of the pollution of the Illinois and Ohio Rivers have indicated that the numbers of bacteria contributed per capita by the sewered populations of various cities are reasonably constant; these numbers change however with seasonal temperature, being much greater in summer than in winter. Such bacteria tend to increase in numbers in the receiving stream for a short period and then decrease at orderly rates as the time from the point of maximum density is increased. These rates of decrease were found to be affected by water temperature and apparently by concentration, being most intensive during the warmer months and under conditions where the density of bacteria was greatest.

Having established definite quantitative relationships from these observations, and assuming that they are fairly representative of stream conditions in general, a method is suggested for estimating the maximum concentration of B.coli in streams of known volume of flow that may be expected to result from pollution contributed by known sewered populations. Furthermore the concentration of such organisms remaining at any point downstream may be estimated providing the velocity of flow is ascertained.

If the observations are representative of general biological laws, they are of practical value for estimating the increasing burden placed on streams receiving the sewage of growing communities and consequently the added loads that water purification plants must be prepared to handle where such polluted watercourses are used as sources of water supply.

TABLE NO. 1

SEASONAL CHANGES IN NUMBERS OF BACTERIA ADDED TO STREAMS BY SEWERED POPULATIONS OF CINCINNATI, LOUISVILLE, CHICAGO AND PEORIA.

Quantity Units of Bacteria per Capita				Billions of Bacteria per Capita per Day		
				Growing on:		
Added by	Gelatin	Agar	B.coli	Gelatin at 20°C. for 48 hrs.	Agar at 37°C. for 24 hrs.	B. coli
Chicago						
Summer	10.148	10.485	0.175	24.828	25,652	428
Winter	1,740	0.346	0.017	4,257	847	42
Year	6.252	4.566	0.094	15,296	11,171	230
Peoria						
Summer	6.447	10.480	0.0912	15,773	25,640	231
Winter	0.869	3.125	0.0577	2,126	7,646	141
Year	4.518	7.894	0.0763	11,054	19,313	187
Cincinnati						
Summer	5.764	7.486	0.238	14,102	18,314	583
Winter	1.058	0.410	0.0486	2,588	1,002	119
Year	4.811	5.009	0.1463	11,770	12,256	358
Louisville						
Summer	5.544	6.475	0.1189	13,564	15,842	291
Winter	3.008	0.3707	0.0789	7,359	907	193
Year	4.431	3.254	0.0907	10,841	7,962	222
Averages						
Summer	6.976	8.731	0.1565	17,067	21,362	383
Winter	1.669	1.063	0.0507	4,083	2,600	124
Year	5.003	5.181	0.1018	12,240	12,676	249

Note: One Quantity Unit = 2,446.589 billions of bacteria per day.

TABLE NO. 2.

MONTHLY VARIATION IN WATER TEMPERATURE AND IN NUMBERS OF B.COLI ADDED TO STREAMS BY SEWERED POPULATIONS OF CITIES.

Average for year = 100.

Month	Cincinnati		Louisville		Chicago		Peoria		Average	
	Water Temperature °C.	Bacteria per cent of annual average	Water Temperature °C.	Bacteria per cent of annual average	Water Temperature °C.	Bacteria per cent of annual average	Water Temperature °C.	Bacteria per cent of annual average	Water Temperature °C.	Bacteria per cent of annual average
Jan.	2.4	29	3.6	60	0.3	12	0.6	2	1.5	26
Feb.	3.3	39	3.3	109	1.0	16	0.4	77	2.0	60
March	4.1	32	4.3	91	3.7	13	4.9	228	4.3	91
April	10.9	53	11.3	69	8.6	33	9.6	13	10.1	42
May	17.9	93	18.5	123	15.0	136	18.6	158	17.5	128
June	23.2	116	23.2	79	20.9	200	24.6	494	23.0	222
July	26.2	185	26.8	174	23.4	393	25.8	51	25.3	201
Aug.	25.5	151	26.3	123	23.8	110	25.5	24	25.3	102
Sept.	23.4	111	23.4	174	20.1	123	23.5	64	22.3	118
Oct.	16.7	252	17.5	108	13.8	98	14.5	30	15.6	131
Nov.	9.3	84	11.0	26	7.4	35	7.8	23	8.8	42
Dec.	3.9	56	5.0	66	3.2	30	4.2	0	4.1	38
Year		100		100		100		100		100

TABLE NO. 3.

SEASONAL VARIATION IN NUMBERS OF BACTERIA CONTRIBUTED TO STREAMS BY SEWERED POPULATIONS.

Yearly average = 100.

Month	Temperature °C.	Per cent of Annual Average		
		Gelatin Count	Agar Count	B.coli
Jan.	1.5	27	13	26
Feb.	2.0	52	20	60
Mar.	4.3	31	22	91
April	10.1	77	32	42
May	17.5	132	107	128
June	23.0	186	227	222
July	25.3	115	168	201
Aug.	25.3	134	188	102
Sept.	22.3	132	161	118
Oct.	15.6	155	166	131
Nov.	8.8	91	69	42
Dec.	4.1	59	27	38
Year		100	100	100

TABLE NO. 4.

COMPARISON OF COMPUTED AND OBSERVED CONCENTRATIONS OF B.COLI CONTRIBUTED BY SEWERED POPULATIONS.

$$\text{B.coli per c.c. (computed value)} = \frac{\text{Population} \times 0.1018 \times \text{Factor}}{\text{Discharge (Thousands of Second-Feet)}}$$

	Temperature range °C.	Factor	Cincinnati (1) Populat'n 494,300			Louisville (2) Popul'n 179,800			Chicago Population 3,834,000			Peoria Popula'n 76,500		
			Discharge Thousand sec-ft	B. coli per c.c. Computed	B. coli per c.c. Actual	Discharge Thousand sec-ft	B. coli per c.c. Computed	B. coli per c.c. Actual	Discharge Thousand sec-ft	B.coli per c.c. Computed	B.coli per c.c. Actual	Discharge Thousand sec-ft	B. coli per c.c. Computed	B. coli per c.c. Actual
Jan.	1.5	0.26	195.8	67	106	108.0	44	91	8.31	9,030	3,890	20.50	99	4
Feb.	2.0	.60	212.7	142	131	221.0	50	80	8.38	20,600	5,200	16.10	290	265
Mar.	4.3	.91	149.7	306	156	192.0	87	77	8.74	30,000	4,050	23.40	303	541
Apr.	10.1	.42	165.5	138	232	297.0	26	38	8.48	14,300	10,400	47.80	68	15
May	17.5	1.28	92.9	693	720	147.0	159	136	8.91	41,400	40,500	24.40	409	358
June	23.0	2.22	68.3	1640	1230	28.8	1410	445	9.37	68,400	56,800	16.90	1020	1622
July	25.3	3.01	47.1	2150	2830	23.1	1590	1230	8.85	65,500	118,000	11.70	1340	241
Aug.	25.3	1.02	38.5	1330	2830	18.3	1020	1090	8.52	34,500	34,500	10.10	786	131
Sept.	22.3	1.18	39.4	2020	2720	20.9	1030	1360	8.23	41,400	39,600	11.90	772	297
Oct.	15.6	1.31	37.2	1770	4900	22.4	1070	786	8.54	44,300	30,500	12.90	790	284
Nov.	8.8	.42	29.5	716	2070	12.3	625	340	8.87	13,700	10,400	16.10	203	78
Dec.	4.1	.38	100.3	191	403	96.5	72	111	8.67	12,600	9,200	25.10	118	--
Year		1.00		929	1530		599	483		33,000	30,300		517	349

(1) Averages for 3 years, 1914, 1915, 1916. (2) Data for year 1914.

TABLE NO. 5.

DECREASE IN AGAR COUNTS, SUMMER SEASON.

(As read from curves)

Time from max. hrs.	Ohio River		Upper Illinois		Lower Illinois	
	Per c.c.	Per cent of max.	Per c.c.	Per cent of max.	Per c.c.	Per cent of max.
0	99,300	100.00	3,890,000	100.0	248,000	100.0
10	66,800	67.26	1,180,000	30.3	121,000	48.7
20	45,100	45.37	640,000	16.45	75,000	30.2
30	30,500	30.71	410,000	10.55	52,000	21.0
40	20,800	20.90	275,000	7.07	38,000	15.3
50	14,200	14.31	197,000	5.06	28,200	11.4
70	6,840	6.89	106,000	2.72	16,500	6.65
100	2,540	2.56	43,000	1.10	7,800	3.14
125	1,290	1.30	20,500	0.526	4,200	1.69
150	755	0.76	9,600	0.247	2,150	0.87
175	497	0.50	4,500	0.116		
200	357	0.36	2,150	0.055		

TABLE NO. 6.

DECREASES IN B.COLI FROM VARIOUS MAXIMUM CONCENTRATIONS, IN RELATION TO TIME OF FLOW. SUMMER SEASON.

Ohio River curve(1)		Upper Illinois		Lower Illinois	
Time from maximum, hours	B. coli per c.c.	Time from maximum, hours	B. coli per c.c.	Time from maximum, hours	B. coli per c.c.
0	3280	0	65,600	0	3550
10	1459	10	22,200	10	1300
20	934	20	11,800	20	620
30	598	30	6,700	30	340
40	385	40	4,100	40	190
70	105	70	1,100	70	40
100	32		385	100	11
125	14		170	125	4
150	8		76		
175	5		34		
200	4		15		

(1) Table No. 125, P. H. Bulletin 143.

TABLE NO. 6, Continued.

DECREASES IN B. COLI FROM VARIOUS MAXIMUM CONCENTRATIONS, IN RELATION TO TIME OF FLOW. SUMMER SEASON.

Ohio River observations grouped by initial concentration (2)

Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.
0	8837	0	4623	0	3557	0	1684	0	1311	0	607	0	339	0	165
				4.7	1746			4.6	1091	2.3	335	3.8	138	2.5	77
				7.3	1560	7.3	961	8.9	728	6.0	286	6.3	100		
		14.9	1741			11.5	1364					12.5	70		
17.7	1460													18.2	70
24.9	1548	22.8	1953					23.5	336	23.6	417				
28.6	1359	29.2	951			25.9	197			27.3	174	28.3	85		
		36.4	604			38.2	178	38.7	396					35.4	51
		43.5	450	49.4	325	45.1	403								
				62.8	439	64.2	88	53.1	75	50.8	98				
		96	122					84.5	70						
110	94			118	21	101	35								
		131	328	136	18										
				159	9										
		255	5												

(2) Data from Table No. 114, P. H. Bulletin 143.

TABLE NO. 7.

DECREASE IN B.COLI FROM VARIOUS MAXIMUM CONCENTRATIONS, IN RELATION TO TIME OF FLOW. Winter Season.

Ohio River curve(1)		Upper Illinois curve		Lower Illinois curve		Ohio River observations grouped by initial concentrations(2)					
Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.	Time from max. hrs.	B. coli per c.c.
0	260	0	7,200	0	180	0	368	0	231	0	173
						4.6	62	3.4	115	3.3	98
						7.4	133	6.6	98	6.0	86
10	156	10	4,220	10	111	13.8	175			13.5	130
										18.8	66
								20.5	117	21.6	70
25	78	25	2,500	25	68			26.1	40	27.3	70
						38.3	46	33.9	86		
						44.3	54			49.7	41
50	31	50	1,400	50	37	59.3	25	64.2	33	51.6	35
75	17	75	890	75	22	83.3	18				
100	12	100	610	100	14	104	8				
125	9	125	422			131	11				
		150	300								
		175	210								
		200	150								

(1) Table No. 127- P.H.Bulletin 143.

(2) Data from Table No.114- P.H.Bulletin 143.

TABLE NO. 8.

NUMBERS OF B. COLI PER C. C. REMAINING AFTER STATED TIMES OF FLOW FROM POINT OF MAXIMUM CONCENTRATION. SUMMER SEASON.

Initial maximum concentration of B.coli	B. coli per c.c. remaining after interval of:								
	10 hrs	25 hrs	50 hrs	75 hrs	100 hrs	125 hrs	150 hrs	175 hrs	200 hrs
75,000	30,000	9,800	2,900	1,000	420	190	84	37	17
60,000	20,000	7,900	2,300	800	350	150	70	32	15
40,000	14,000	5,900	2,000	600	270	120	57	27	14
20,000	7,600	3,000	1,070	420	190	94	47	25	13
10,000	4,000	1,600	640	270	130	68	36	20	12
5,000	2,300	1,100	410	170	78	42	24	15	12
1,000	440	210	80	30	13	5			
500	260	130	70	25	8				
100	40	20	12						

TABLE NO. 9.

NUMBERS OF B. COLI PER C.C. REMAINING AFTER STATED TIMES OF FLOW FROM POINT OF MAXIMUM CONCENTRATION. WINTER SEASON.

Initial maximum concentration of B.coli	B. coli per c.c. remaining after interval of:								
	10 hrs	25 hrs	50 hrs	75 hrs	100 hrs	125 hrs	150 hrs	175 hrs	200 hrs
10,000	6,000	3,500	2,000	1,200	840	600	420	300	200
5,000	3,000	1,800	960	600	400	300	200	140	100
1,000	520	280	140	80	54	38	26		
500	240	120	60	32	21	15			
100	62	40	20	12	7				

FIGURE NO. 1.
Seasonal Variation in Bacteria Contributed to Streams by Sewered Populations of Cities.

LEGEND:
Gelatin: ——————
Agar: - - - - - -
B. coli: —— —— ——

Per Cent of Annual Average; Annual Average = 100

225
200
175
150
125
100
75
50
25
0

Jan. Feb. Mar. Apr. May June July Aug. Sept. Oct. Nov. Dec.

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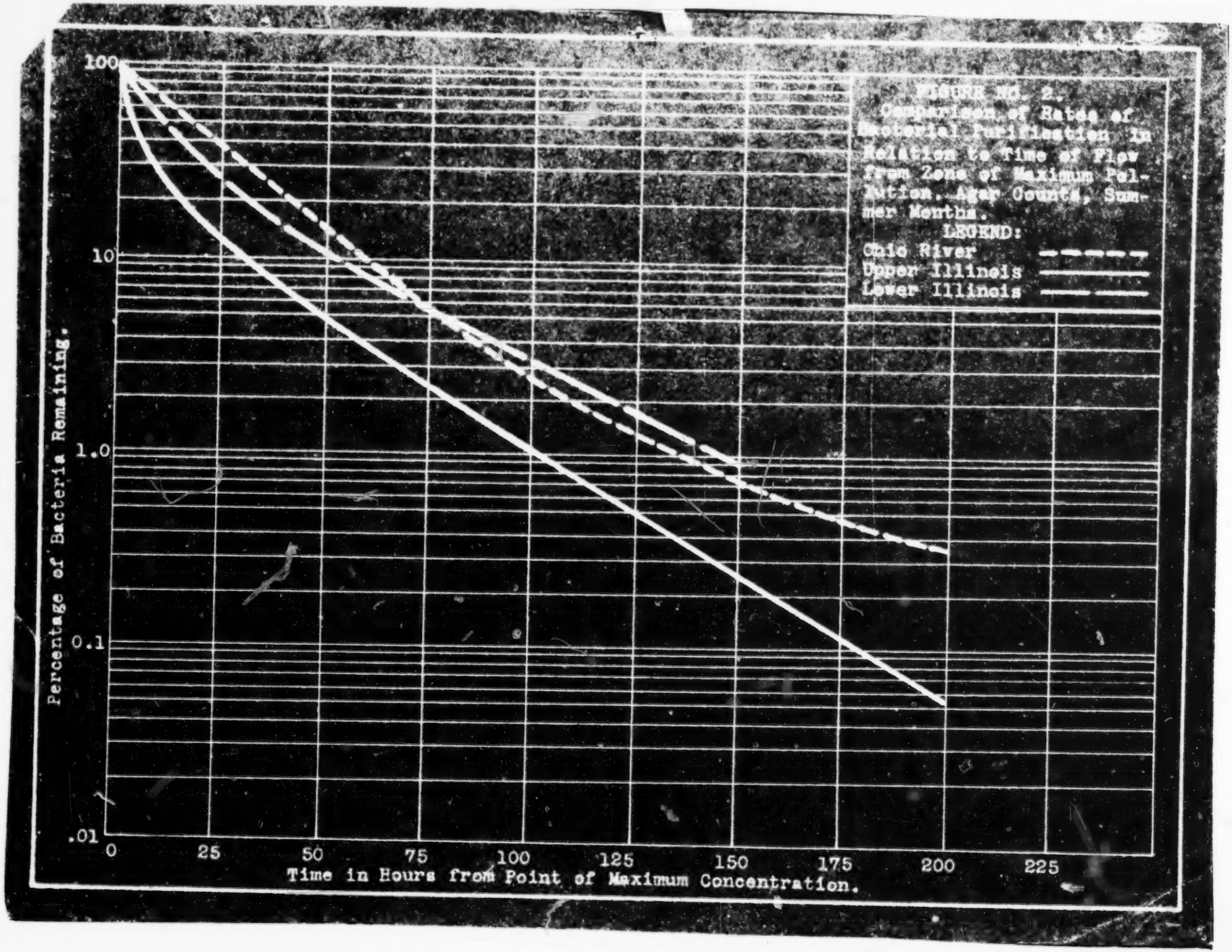
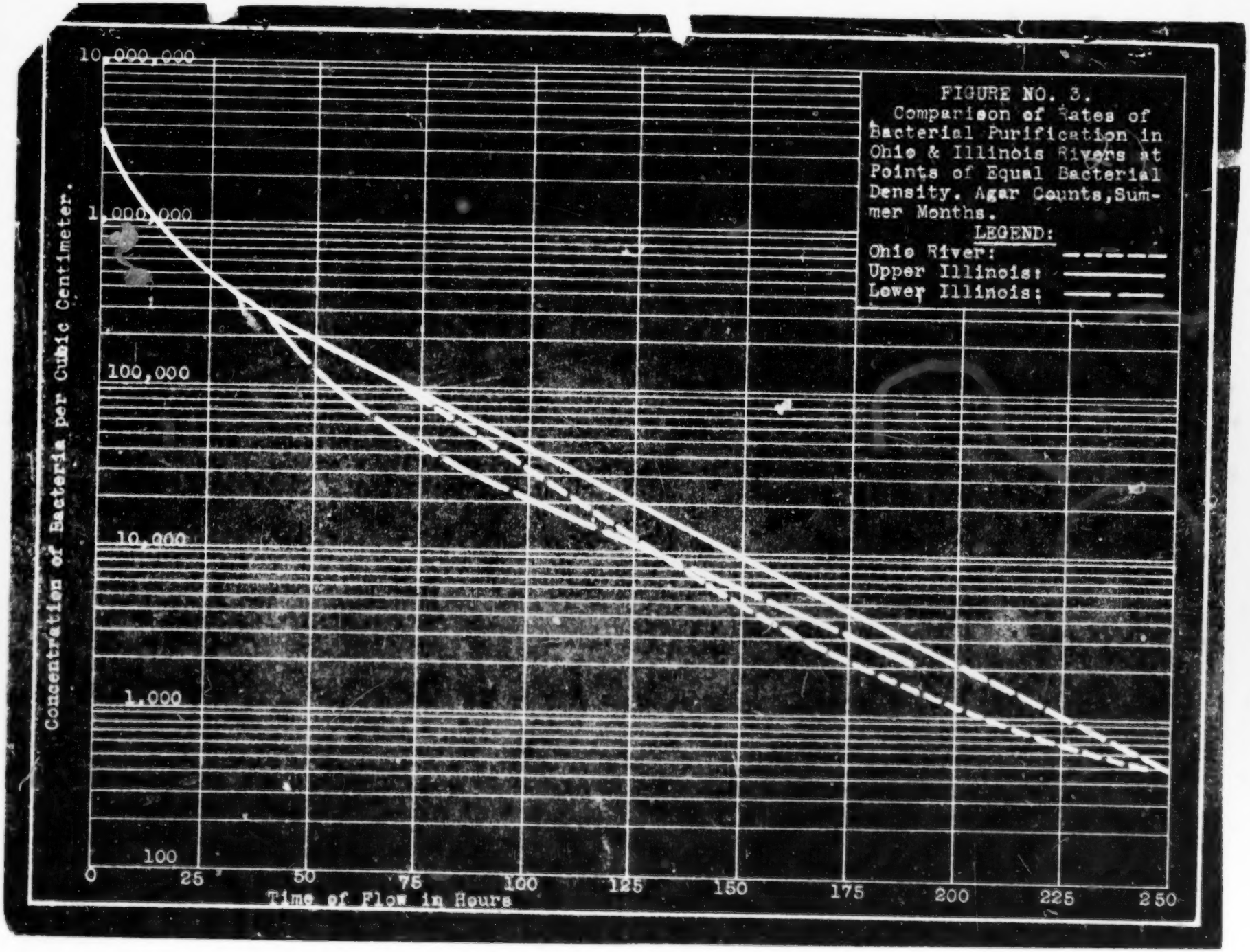


CHART NO. 2.
Comparison of Rates of Bacterial Purification in Relation to Time of Flow from Zone of Maximum Pollution. Agar Counts, Summer Months.
LEGEND:
Ohio River
Upper Illinois
Lower Illinois
Percentage of Bacteria Remaining.
100
10
1.0
0.1
.01
0
25
50
75
100
125
150
175
200
225
Time in Hours from Point of Maximum Concentration.


10,000,000
1,000,000
100,000
10,000
1,000
100
0
25
50
75
100
125
150
175
200
225
250
Concentration of Bacteria per Cubic Centimeter.
Time of Flow in Hours
FIGURE NO. 3.
Comparison of Rates of Bacterial Purification in Ohio & Illinois Rivers at Points of Equal Bacterial Density. Agar Counts, Summer Months.
LEGEND:
Ohio River:
Upper Illinois:
Lower Illinois: